Diagnosis of Tropical Cyclone Structure and Intensity Change

Daniel Keyser
Department of Earth and Atmospheric Sciences, ES-224
University at Albany, State University of New York
1400 Washington Avenue
Albany, NY 12222
Phone: (518) 442-4559 Fax: (518) 442-4494
E-mail: keyser@atmos.albany.edu
Grant Number: N00014-92-J-1532
http://www.atmos.albany.edu/facstaff/keyser.html

LONG-TERM GOALS

To improve and refine understanding of the dynamics of tropical-cyclone structure and intensity change. A guiding theme of this research effort is to apply and extend well-established dynamical perspectives on extratropical cyclogenesis and cyclone life cycles, particularly in maritime regions, to the tropics.

OBJECTIVES

a. To investigate the origin and evolution of tropopause-based precursor disturbances that culminate in rapid maritime cyclogenesis over the western North Atlantic Ocean.

b. To investigate the roles of trough interactions in tropical-cyclone intensity change with a view toward determining the factors that distinguish between cyclogenetic and cyclolytic trough interactions.

c. To investigate the roles of environmental dynamical effects on tropical-cyclone structure and intensity change.

d. To investigate the kinematics of vorticity asymmetries associated with nondivergent barotropic vortices on a β-plane.

APPROACH

Objectives (a) and (b) are conducted through extensive diagnostic analysis of gridded datasets produced by the National Centers for Environmental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF). Objective (a) is performed in collaboration with Professor Gary M. Lackmann (State University of New York, College at Brockport); objective (b) is undertaken in collaboration with Professor John Molinari and Deborah E. Hanley (University at Albany, State University of New York). Objective (c) is conducted using an idealized three-layer shallow-water numerical model that includes parameterizations of convection, sea surface energy exchange, and surface friction. Objective (c) is addressed by Dr. Klaus Dengler and the principal investigator (University at Albany, State University of New York). Objective (d) is performed using analytical and numerical solutions of the barotropic vorticity equation in collaboration with Professor Roger K. Smith (University of Munich).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **Diagnosis of Tropical Cyclone Structure and Intensity Change**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University at Albany/Suny,Department of Earth and Atmospheric Sciences,1400 Washington Avenue,Albany,NY,12222**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

a. A representative event that occurred during the second intensive observation period (IOP 2) of the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA, December 1988–February 1989) has been analyzed from the perspective of local energetics.

b. Consideration of all named tropical cyclones that occurred over the North Atlantic basin from 1985 through 1996 has led to a proposed classification scheme for tropical-cyclone intensity change that consists of six characteristic types.

c. An idealized three-layer shallow-water numerical model has been applied to investigate the effect of zonal background flows on the intensification of tropical-cyclone-like vortices for f- and β-plane geometries.

d. A diagnostic methodology has been developed for characterizing the anisotropy of nondivergent flow fields in a pointwise sense and illustrated for β-gyres in a barotropic model of a tropical-cyclone-like vortex.

RESULTS

a. Energetics of tropopause-based precursor disturbances

A characteristic life cycle of upper-tropospheric cyclogenetic precursors involves the development of an elongated region of lower dynamic tropopause that forms in association with an intensifying midtropospheric jet/front. A representative event of this type that occurred during ERICA IOP 2 has been examined from the perspective of local energetics, allowing determination of the mechanisms that led to jet streak intensification and documentation of the three-dimensional eddy kinetic energy (EKE) distribution within the developing jet/front system. Analysis of the Reynolds stress reveals that the contribution of this term is determined primarily by the relative orientation of the perturbation horizontal wind velocity and the dilatation axis of the time-mean flow. In regions where the perturbation wind velocity is oriented within 45° of normal to the dilatation axis of the time-mean flow, the contribution of the Reynolds stress to the EKE tendency is positive. The presence of a ridge over western North America favors jet streak intensification through the Reynolds stress as northerly perturbation flow east of the ridge axis possesses a favorable orientation with respect to the dilatation axes of the time-mean flow over central North America. Local EKE increases accompany strengthening transverse divergent circulations, facilitating the downward advection of stratospheric values of potential vorticity and eventually resulting in the development of a mobile upper trough. This sequence is consistent with the preference for mobile upper-trough genesis over central North America in the presence of a northerly flow component, a finding documented previously by Sanders.

b. Role of trough interactions in tropical-cyclone intensity change

Previous case studies performed as part of this effort have shown that favorable trough interactions are characterized by relatively small-to-moderate values of vertical wind shear associated with shallow potential vorticity (PV) anomalies. When PV anomalies are restricted to the outflow layer of the tropical cyclone, diabatic erosion of PV can weaken the PV anomaly and thereby diminish the vertical wind shear in the vicinity of the tropical cyclone. In contrast, unfavorable trough interactions are characterized by large values of vertical wind shear associated with deep PV anomalies that extend below the layer where diabatic heating can reduce the strength of the PV anomaly.

The foregoing preliminary findings are extended to a larger sample of cases by considering all named tropical cyclones that occurred over the North Atlantic basin from 1985 through 1996. A trough interaction event is defined where the eddy flux convergence (EFC) at 200 hPa over a 300–600 km storm-centered radial band exceeds 10 m s^{-1} d^{-1} and the total surface pressure change during the interaction exceeds 10 hPa. Consideration of the larger sample of cases has resulted in a classification scheme for tropical-cyclone intensity change. In the first four categories of this scheme the tropical cyclone intensifies, whereas in the fifth and sixth the tropical cyclone weakens. The first, second, third, and fifth categories satisfy the definition of a trough interaction, whereas the fourth and sixth do not involve the presence of a trough. The categories are: (i) superposition (upper-tropospheric positive PV anomaly within 400 km of storm center); (ii) distant interaction (PV anomaly between 400 and 1000 km of storm center); (iii) extratropical transition (intensification following transition); (iv) favorable/no trough (intensification with EFC less than 5 m s^{-1} d^{-1} for at least three consecutive 12 h periods); (v) unfavorable trough interaction (weakening with enhanced EFC); and (vi) unfavorable/no trough (weakening with EFC less than 5 m s^{-1} d^{-1} for at least three consecutive 12 h periods). Composites for each of these characteristics types of tropical-cyclone intensity change have been calculated. The respective composites are being analyzed in further detail using Eliassen-Palm flux diagnostics and a decomposition of the wind field into rotational and divergent parts.

c. Intensification of tropical-cyclone-like vortices in zonal background flows

The effect of uniform zonal background flows on the intensification of tropical-cyclone-like vortices is investigated using a numerical three-layer shallow-water model that includes parameterizations of convection, sea surface energy exchange, and boundary-layer friction. Calculations on an *f*-plane show that during the developing stage, an initially weak vortex intensifies more rapidly in the presence of a uniform zonal background flow regardless of its direction. Compared to an environment at rest, the uniform zonal background flow results in increased boundary-layer convergence colocated with increased boundary-layer mixing ratio due to surface moisture fluxes, producing stronger convection and therefore more rapid intensification. After the vortex achieves hurricane strength in the presence of an easterly (westerly) background flow, a region of convectively stable air forms to the south (north) of the vortex center as a result of low surface moisture fluxes and the downward transport of relatively dry middle-layer air. This convectively stable air penetrates slowly into regions of boundary-layer convergence, thereby weakening convection and reducing the maximum intensity of the tropical-cyclone-like vortices embedded in uniform zonal background flows. This effect is found to be more pronounced for stronger uniform background flows.

Calculations on a β-plane show that a westerly background flow is more favorable for intensification than an easterly background flow of the same strength. This dependence of intensification rate on the direction of the background flow is shown to be due to differences in the position of a region of convectively unstable air relative to the trajectory of the vortex in these respective cases. In the westerly background flow case, the vortex always moves into a region of convectively unstable air, whereas in the easterly background flow case, the vortex progressively moves into a region of convectively stable air produced by subsidence and drying of the boundary layer. Because of the relatively high vortex drift speed in the easterly background flow case, there is not sufficient time for surface moisture fluxes to moisten the dry boundary-layer air rapidly enough to eliminate the convectively stable region ahead of the vortex, resulting in the overall weakening of convective activity and a less intense storm than in the westerly flow case. The foregoing calculations suggest that the imposed background flow affects the development of the vortices in the shallow-water model by establishing an environment in which boundary-layer convergence and surface moisture fluxes may interact to produce stratifications that either enhance or suppress convection, which ultimately controls the intensification of the vortices in the model.

d. Kinematics of vorticity asymmetries associated with nondivergent barotropic vortices on a β-plane.

A diagnostic methodology has been developed for characterizing the anisotropy of nondivergent flow fields in a pointwise sense and is applied to the β-gyres in a barotropic model of tropical-cyclone-like vortices. This methodology makes use of a new type of natural-coordinate system motivated by Petterssen's classic treatment of linearly varying horizontal wind fields, where the coordinate axes are oriented along and across the locally preferred direction of a flow feature. In this application, the relative vorticity field is partitioned into components associated with the along- and across-gyre directions, such that the across-gyre vorticity is a maximum relative to the along-gyre vorticity in a pointwise sense. These respective vorticity fields may be inverted to yield flows over the vortex center, quantifying the influence of the anisotropy of the β-gyres on vortex motion. The partition of vortex motion into along- and across-gyre components indicates the dominance of the latter, consistent with the azimuthally elongated structure of the vorticity asymmetries that induce the β-gyres. The potential significance and novelty of this diagnostic methodology is that it offers a framework for relating the strength and configuration of the flow induced by a vortex to its anisotropy, which now may be quantified locally instead of globally (i.e., in terms of a single aspect ratio characterizing the entire vortex). This methodology may prove useful in diagnosing vertical interactions among vortices during tropical-cyclone intensity change, since the strength of vertical coupling is hypothesized to be related to vortex anisotropy. Moreover, the proposed methodology is not restricted to the present application, which is concerned with nondivergent wind fields, but may be generalized to apply to horizontal wind fields containing divergence on both regional and global domains. The further possibility exists to modify the proposed methodology to determine the preferred directions of vertical velocity and pressure tendency patterns.

IMPACT/APPLICATIONS

The various diagnostic methodologies developed and implemented during the course of this research effort may be considered for eventual application in a real-time forecasting environment. The outcome of the research effort concerned with distinguishing between favorable and unfavorable trough interactions in tropical-cyclone intensity change should be of practical interest to operational forecasters. The interpretations of tropical-cyclone intensity change emerging from the idealized numerical modeling investigation offer a conceptual bridge between analytically based theoretical models and realistic numerical prediction models applied to forecasting tropical-cyclone intensity change in experimental and operational settings.

TRANSITIONS

The ageostrophic circulation diagnostic package used in the present project, which was developed previously by the principal investigator and graduate students at the University at Albany, is being applied by Professor John Molinari's research group to diagnose observed trough-interaction events. On Tuesday 12 May 1998, Dr. Klaus Dengler presented an invited seminar at NRL/Monterey entitled, "Intensification of Tropical-Cyclone-Like Vortices in Zonal Background Flows," and discussed the results of the effort involving the numerical three-layer shallow-water model with various scientific staff members at NRL/Monterey.

The present project involves collaborative efforts with Professors John Molinari (University at Albany) and Roger K. Smith (University of Munich), both of whom are funded by the ONR Marine Meteorology Program. These respective collaborations are concerned with the trough-interaction problem, addressed through diagnostic studies of observed events and idealized numerical model experiments designed to elucidate the dynamics of the trough-interaction process.

PUBLICATIONS

Dengler, K., and R. K. Smith, 1998: A monsoon depression over northwestern Australia. Part II: A numerical model study. *Aust. Meteor. Mag.*, **47**, 135–144.

Keyser, D., 1998: On the representation and diagnosis of frontal circulations in two and three dimensions. *The Life Cycles of Extratropical Cyclones*, M. A. Shapiro and S. Grønås, Eds., Amer. Meteor. Soc. (in press).

Dengler, K., and D. Keyser, 1998: Intensification of tropical-cyclone-like vortices in uniform zonal background flows. *Quart. J. Roy. Meteor. Soc.*, **124** (submitted).

Lackmann, G. M., D. Keyser, and L. F. Bosart, 1998: Energetics of an intensifying jet streak during the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA). *Mon. Wea. Rev.*, **126** (submitted).

IN-HOUSE/OUT-OF-HOUSE RATIOS

This effort is performed exclusively at academic institutions (0% in-house, 100% out-of-house): 85% at the University at Albany, State University of New York; 15% at the University of Munich.